US007795805B2

(12) **United States Patent**
Kim

(10) **Patent No.: US 7,795,805 B2**
(45) **Date of Patent: Sep. 14, 2010**

(54) **ORGANIC LIGHT EMITTING DEVICE AND METHOD OF MANUFACTURING THE SAME**

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(73) Assignee: **LG Display Co., Ltd.**, Seoul (KR)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 666 days.

(21) Appl. No.: **11/802,538**

(22) Filed: **May 23, 2007**

(65) **Prior Publication Data**

US 2008/0001531 A1 Jan. 3, 2008

(30) **Foreign Application Priority Data**

Jun. 20, 2006 (KR) 10-2006-055239
May 11, 2007 (KR) 10-2007-046037

(51) **Int. Cl.**
H01L 51/54 (2006.01)

(52) **U.S. Cl.** **313/504**; 428/690

(58) **Field of Classification Search** 313/500–512
See application file for complete search history.

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(57) **ABSTRACT**

An organic light emitting device includes a first electrode for providing holes, a second electrode facing the first electrode and providing electrons, an organic luminescent layer interposed between the first and second electrodes, and an electron transfer layer disposed between the second electrode and the organic luminescent layer, wherein the electron transfer layer is a single layer including electron transfer members so that the electron transfer layer injects and transports electrons to the organic luminescent layer while preventing holes from the first electrode from flowing into the electron transfer layer.

19 Claims, 9 Drawing Sheets

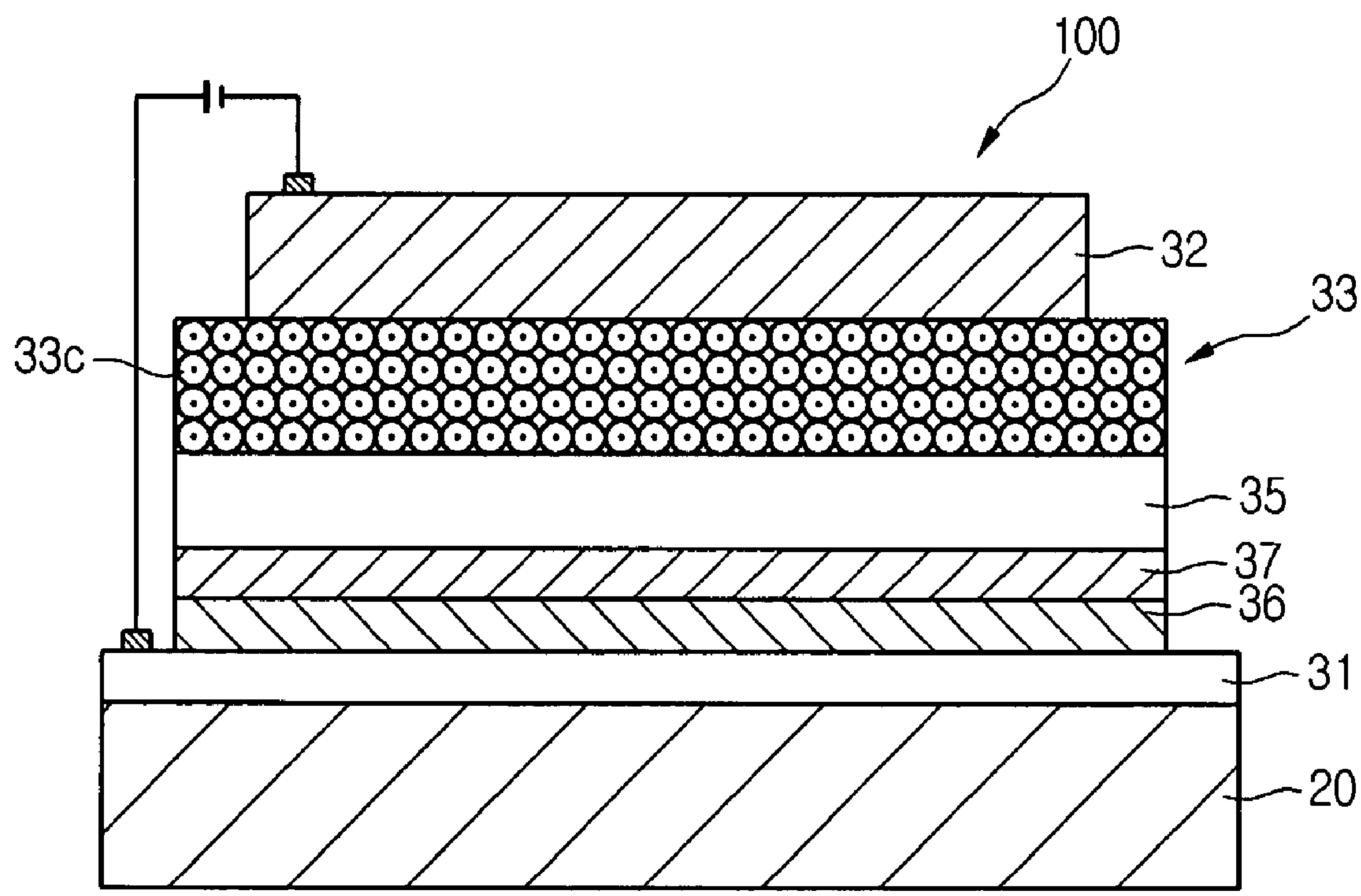


FIG. 1

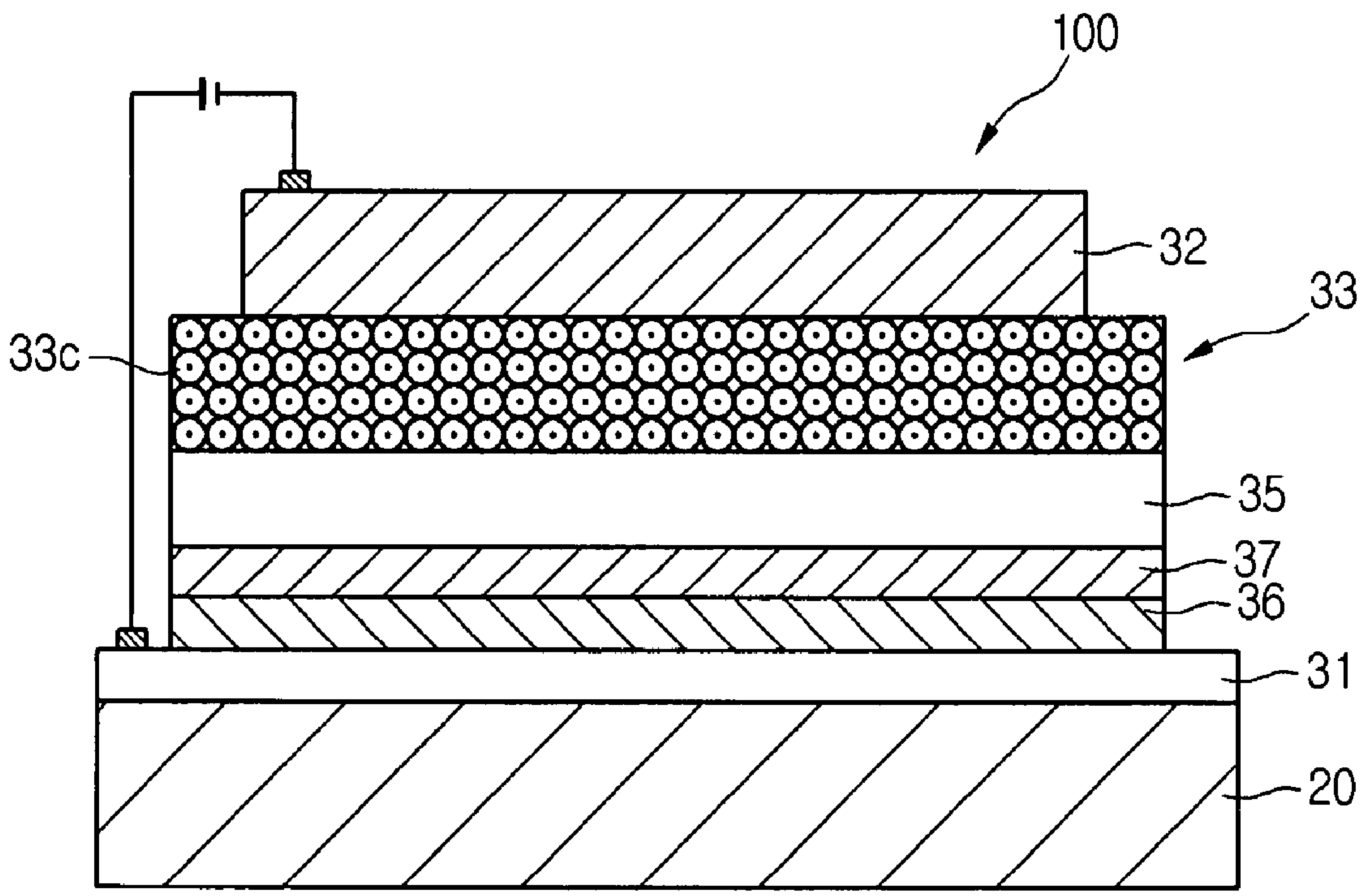


FIG. 2

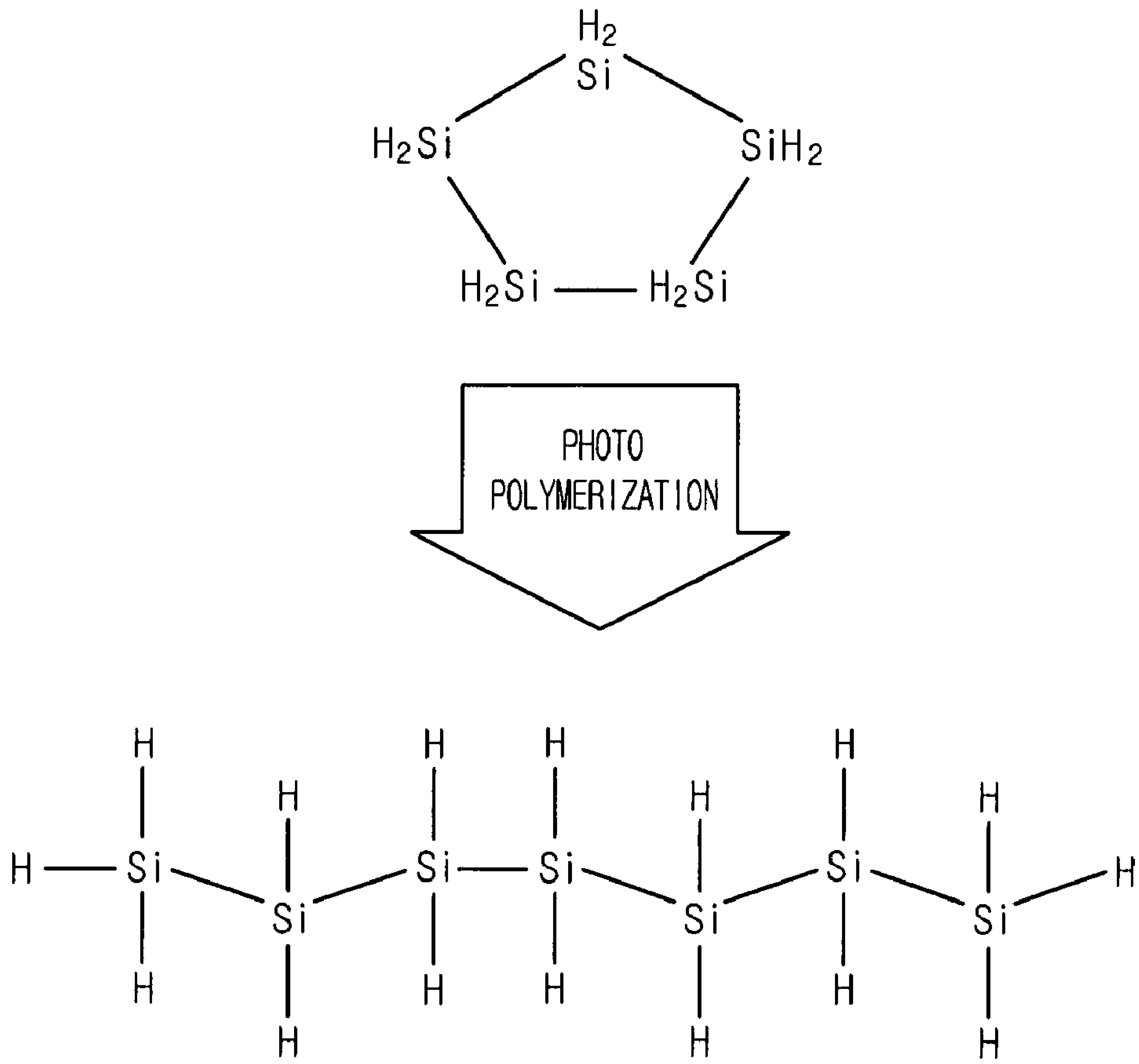

H2
Si
H2Si
SiH2
H2Si
H2Si
PHOTO
POLYMERIZATION
H
Si

FIG. 3

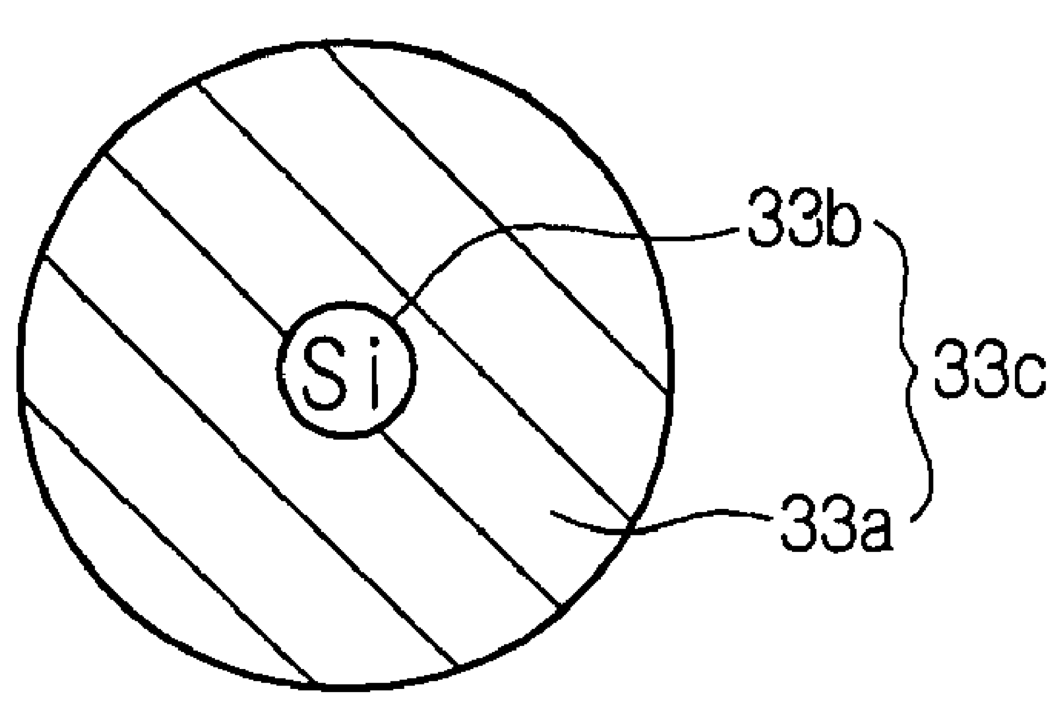

Si
33b
33c
33a

FIG. 4

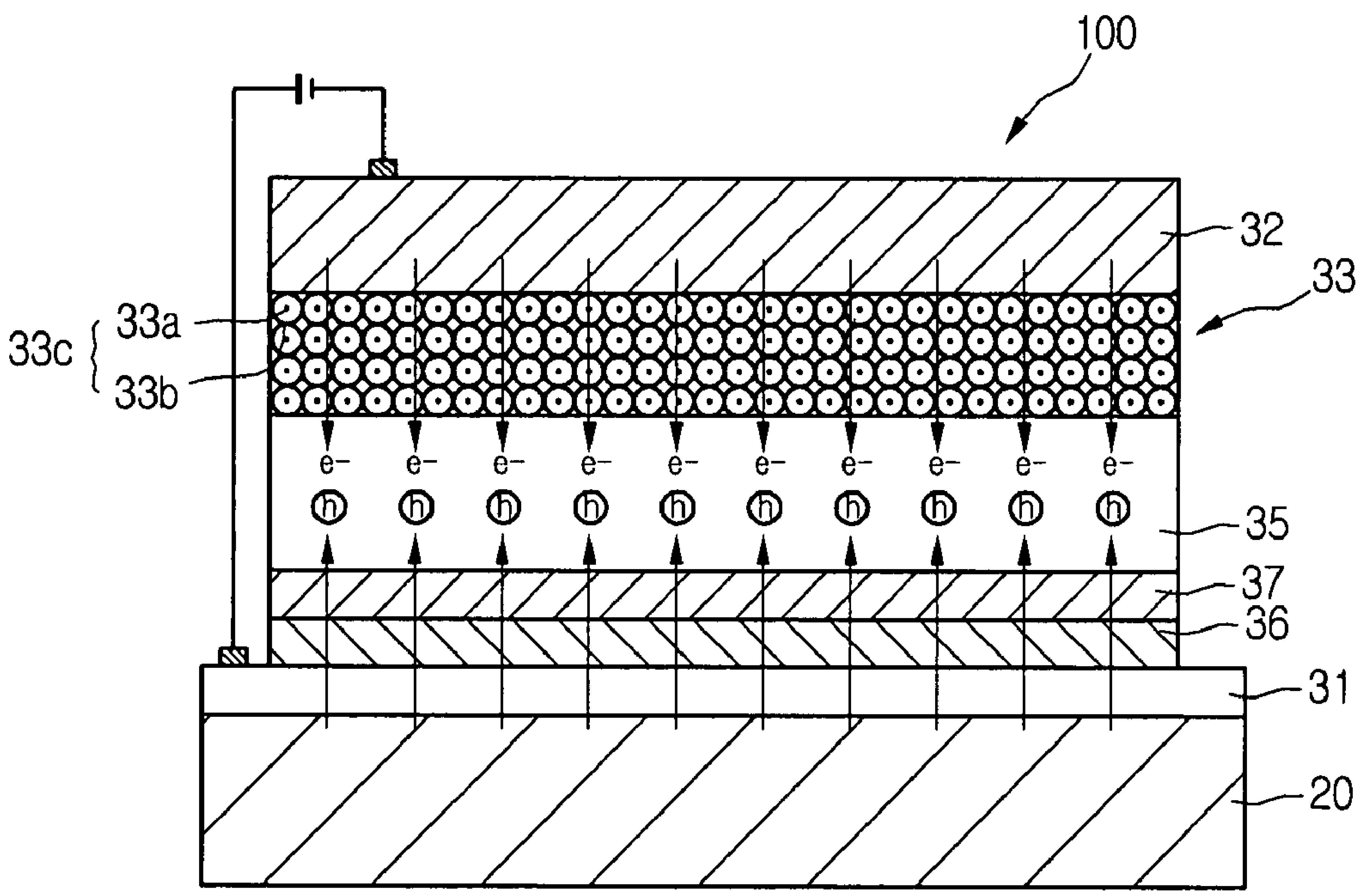


FIG. 5

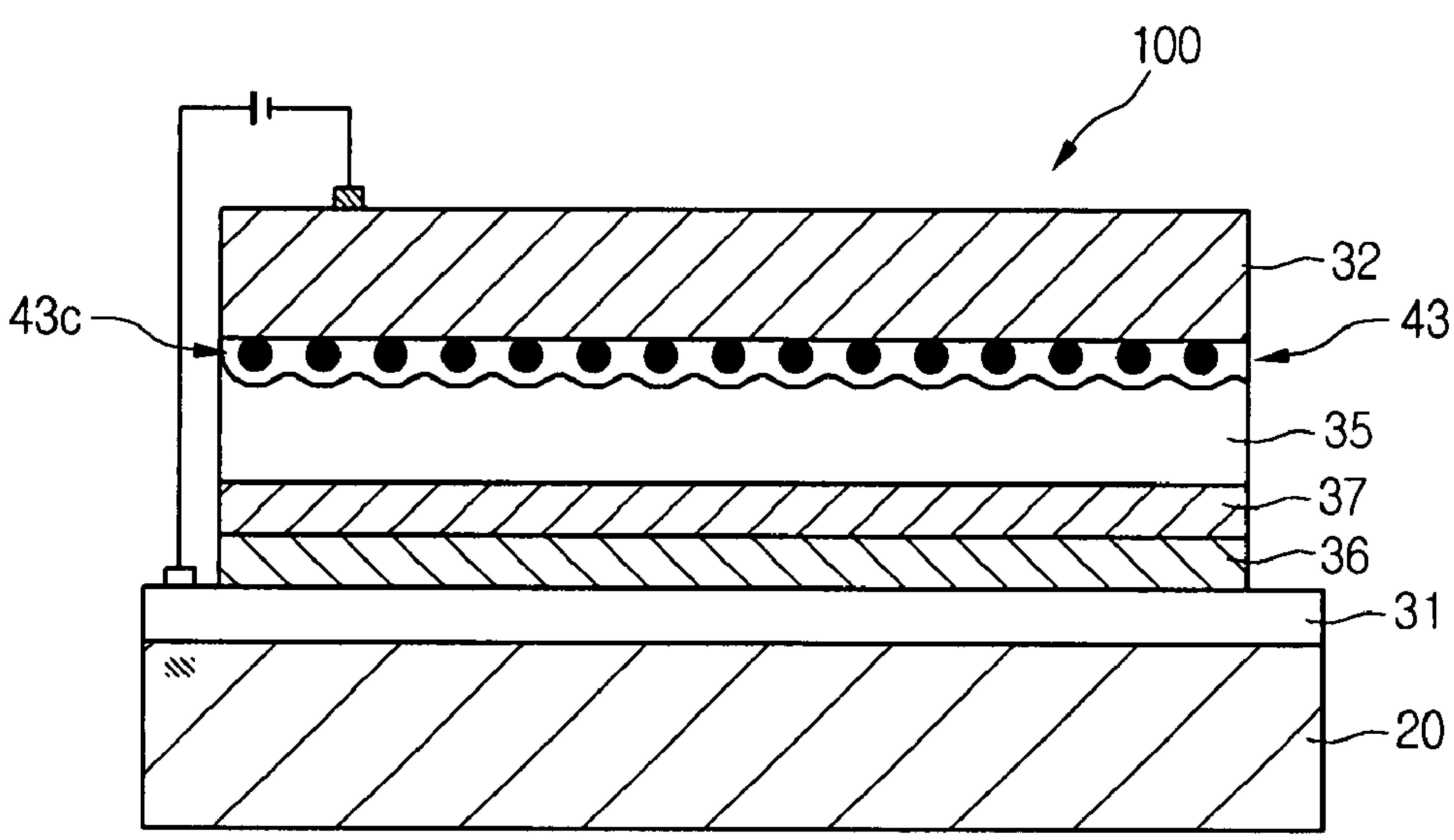


FIG. 6

FIG. 7

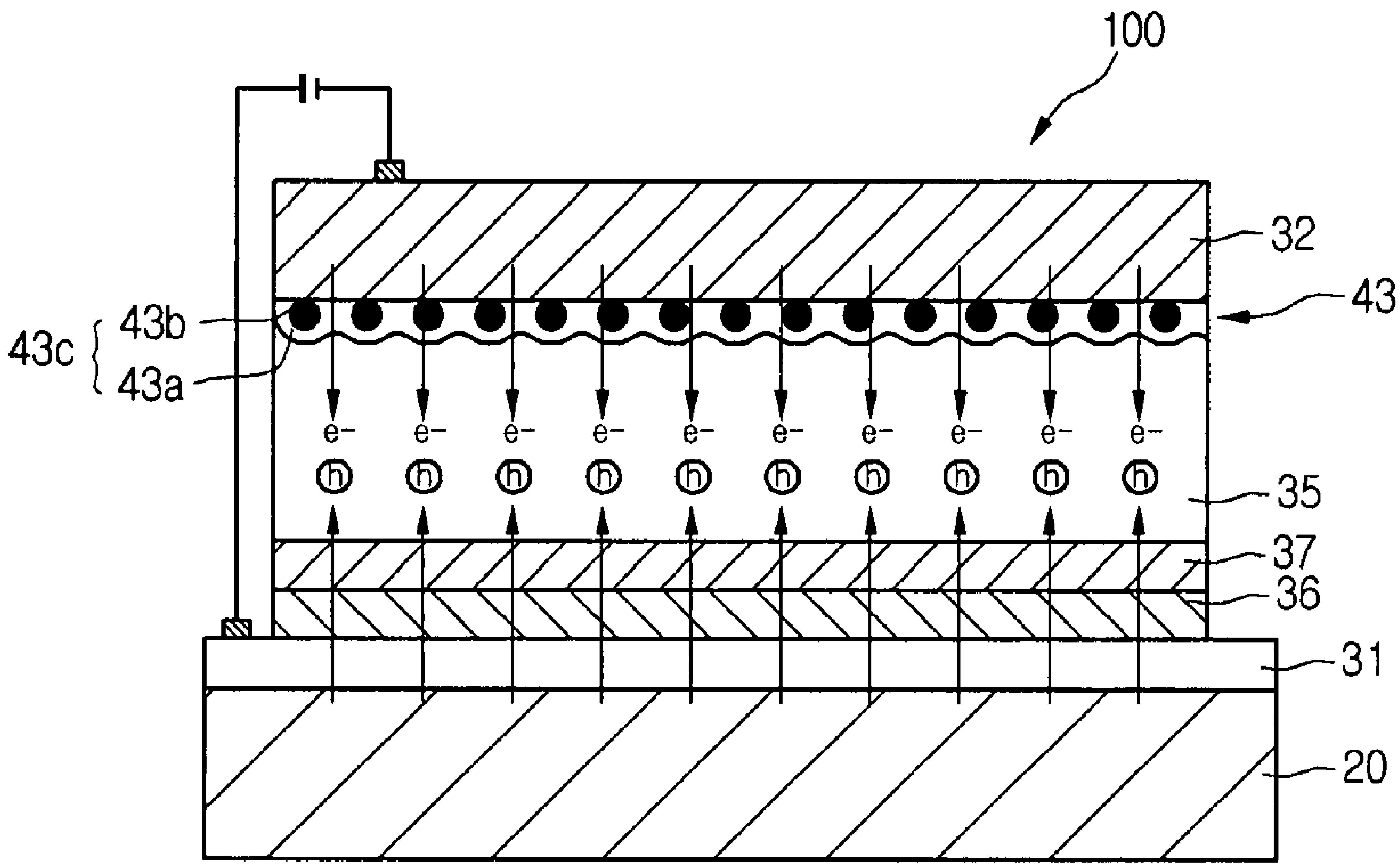


FIG. 8A

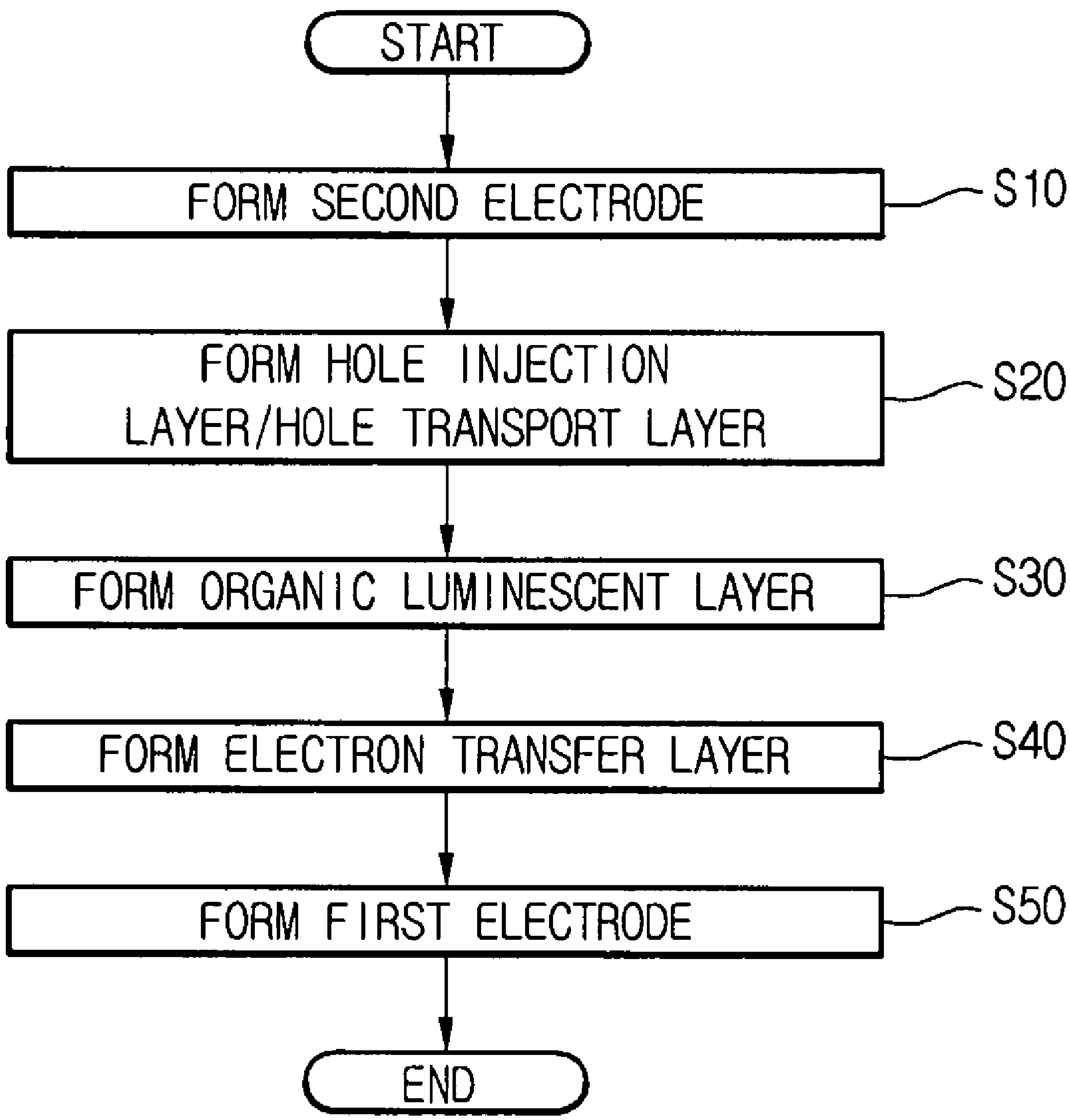

START
FORM SECOND ELECTRODE
S10
FORM HOLE INJECTION LAYER/HOLE TRANSPORT LAYER
S20
FORM ORGANIC LUMINESCENT LAYER
S30
FORM ELECTRON TRANSFER LAYER
S40
FORM FIRST ELECTRODE
S50
END

FIG. 8B

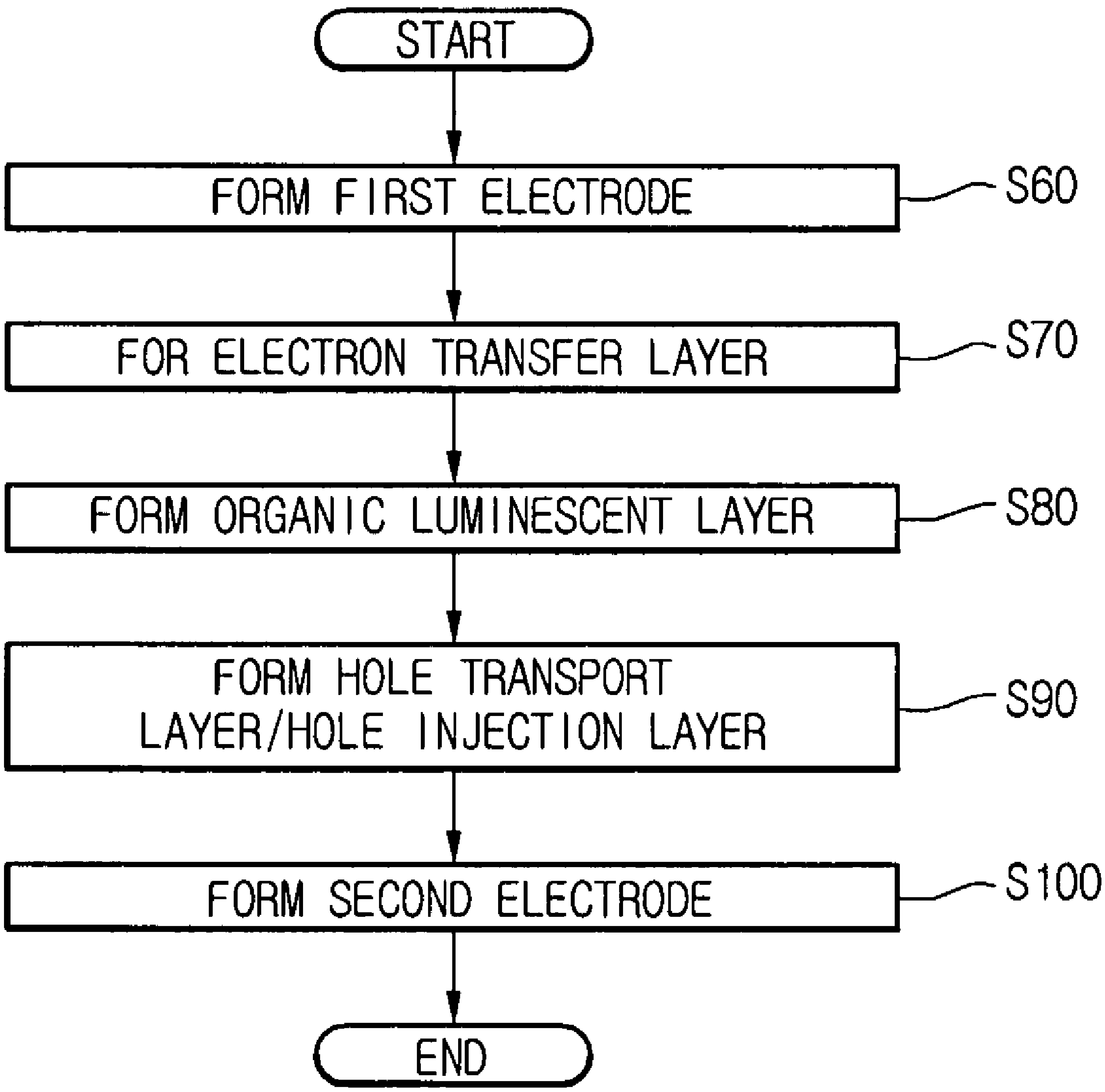
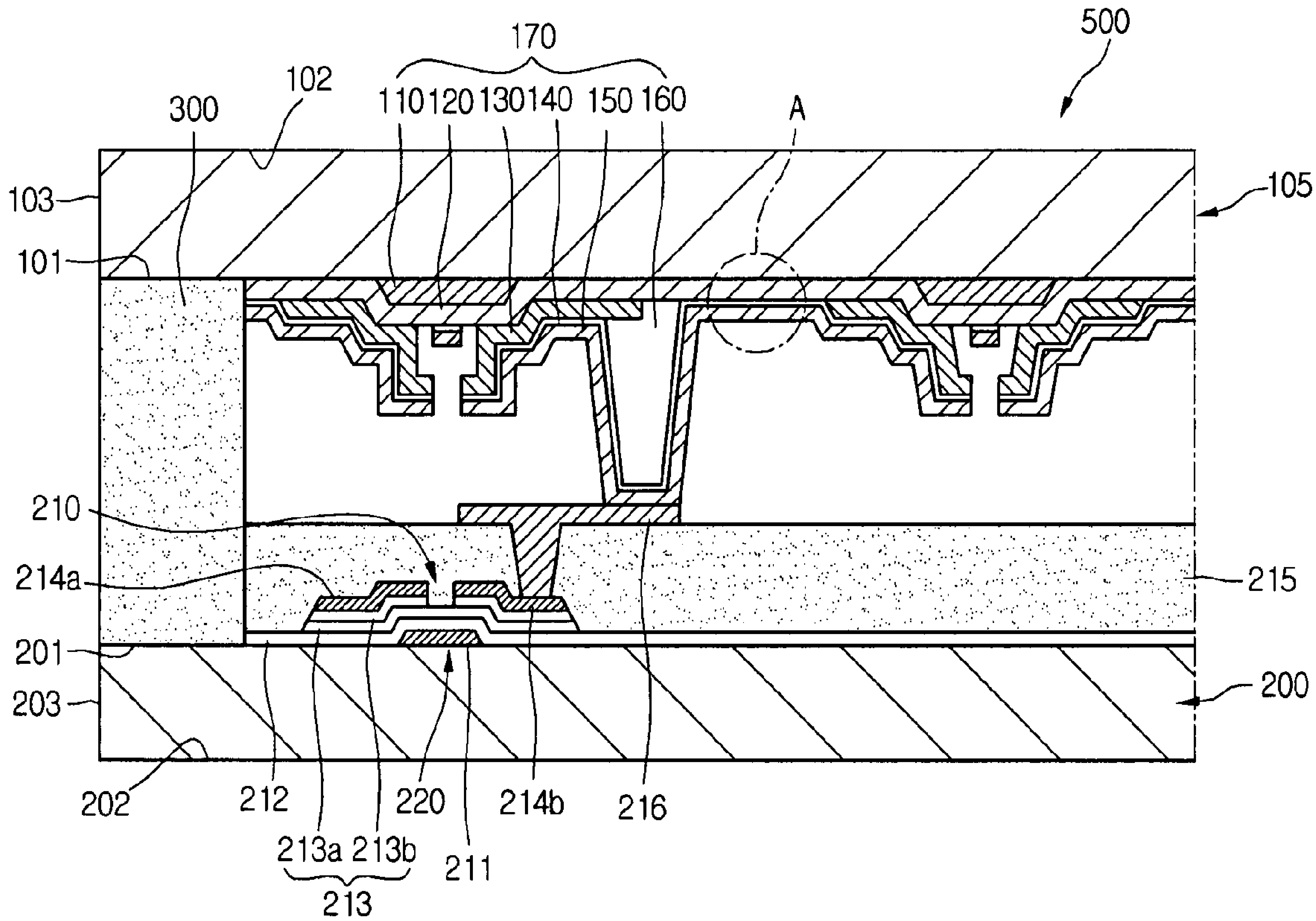
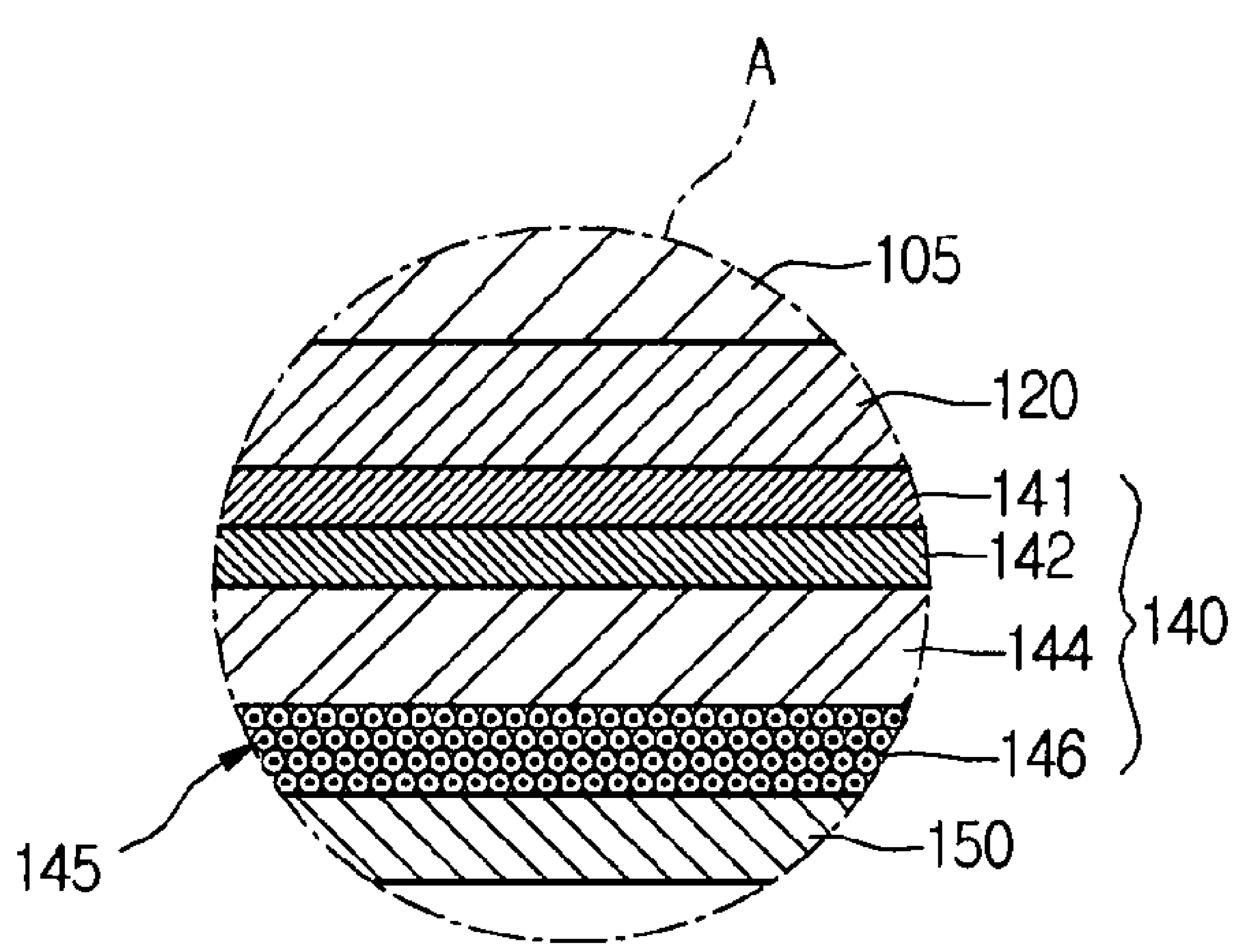

START
FORM FIRST ELECTRODE
S60
FOR ELECTRON TRANSFER LAYER
S70
FORM ORGANIC LUMINESCENT LAYER
S80
FORM HOLE TRANSPORT LAYER/HOLE INJECTION LAYER
S90
FORM SECOND ELECTRODE
S100
END

FIG. 9



170
500
102
300
110
120
130
140
150
160
A
103
105
101
210
214a
215
201
200
203
202
212
220
214b
216
213a
213b
211
213

FIG. 10A



A
105
120
141
142
140
144
146
145
150

FIG. 10B

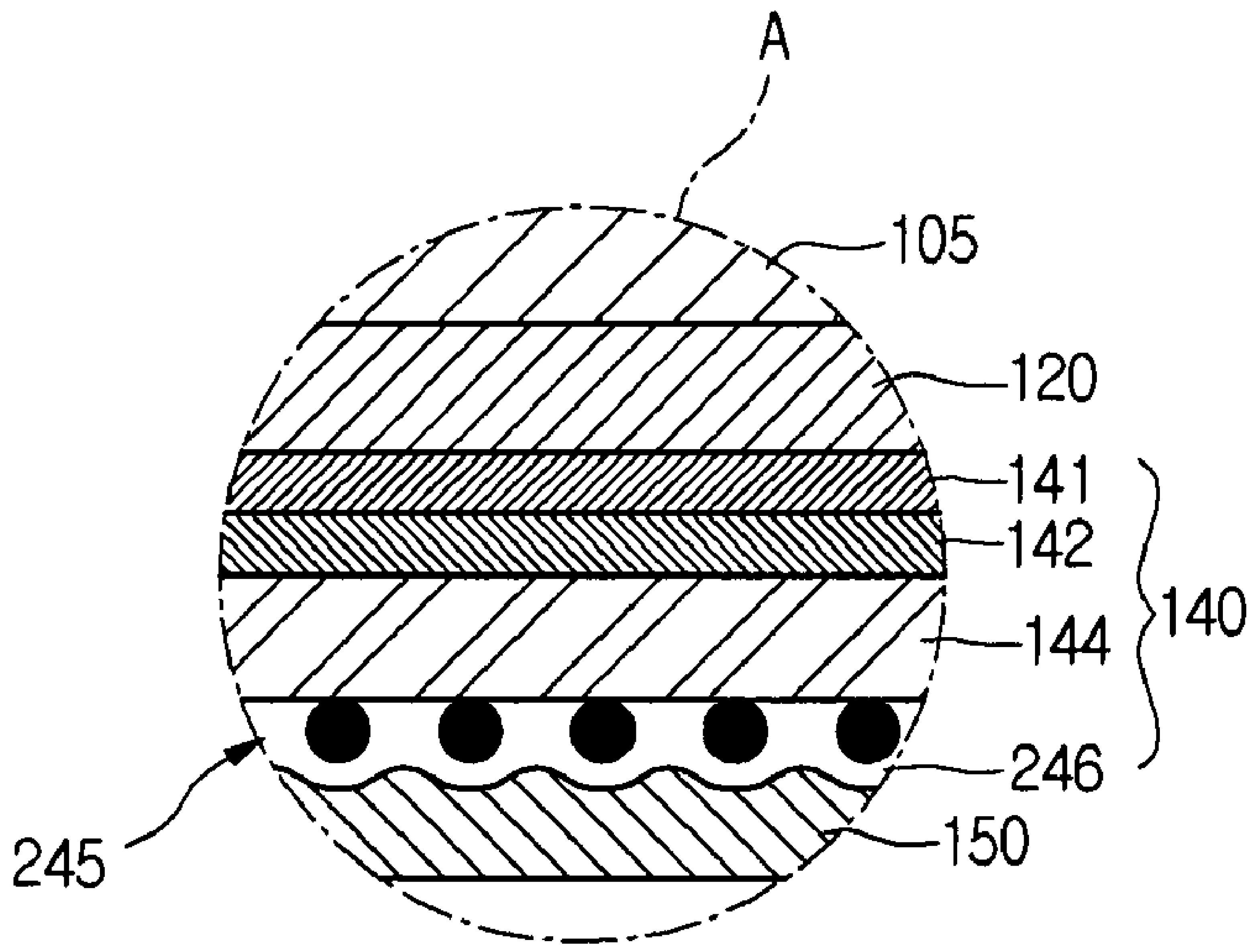


FIG. 11

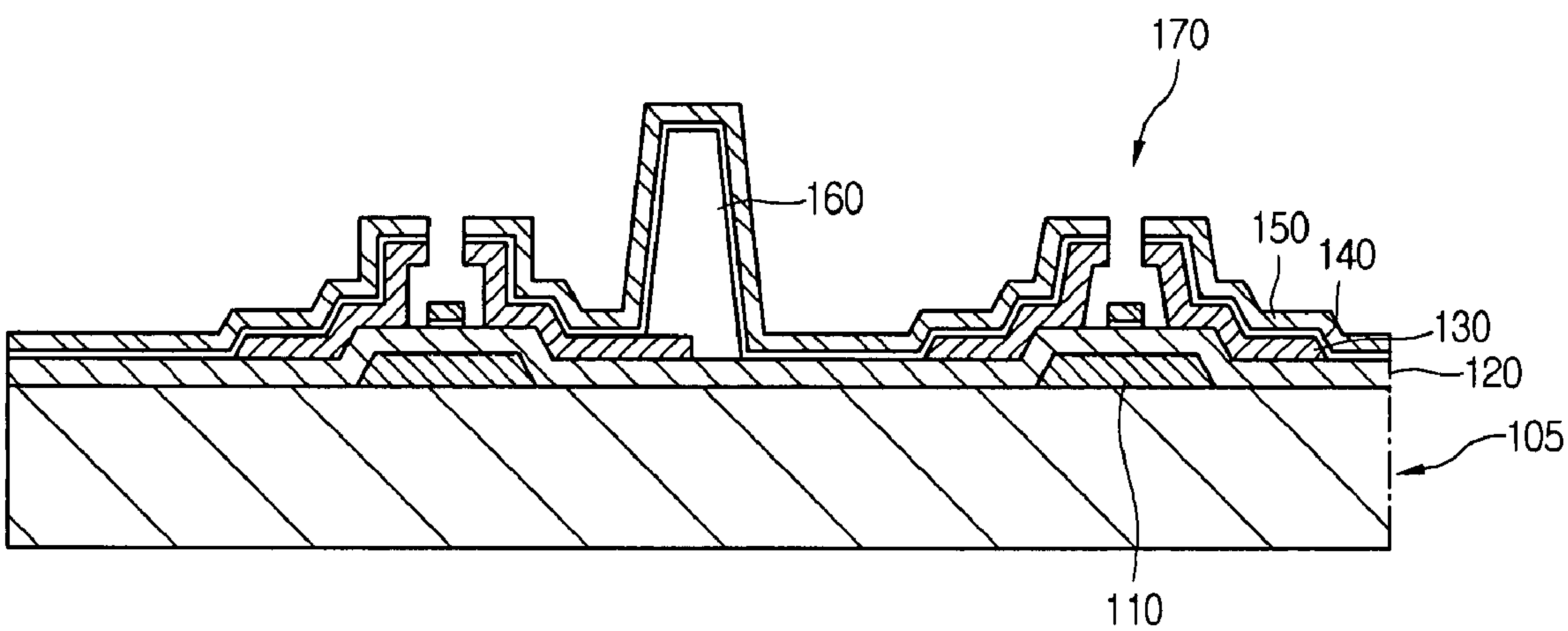
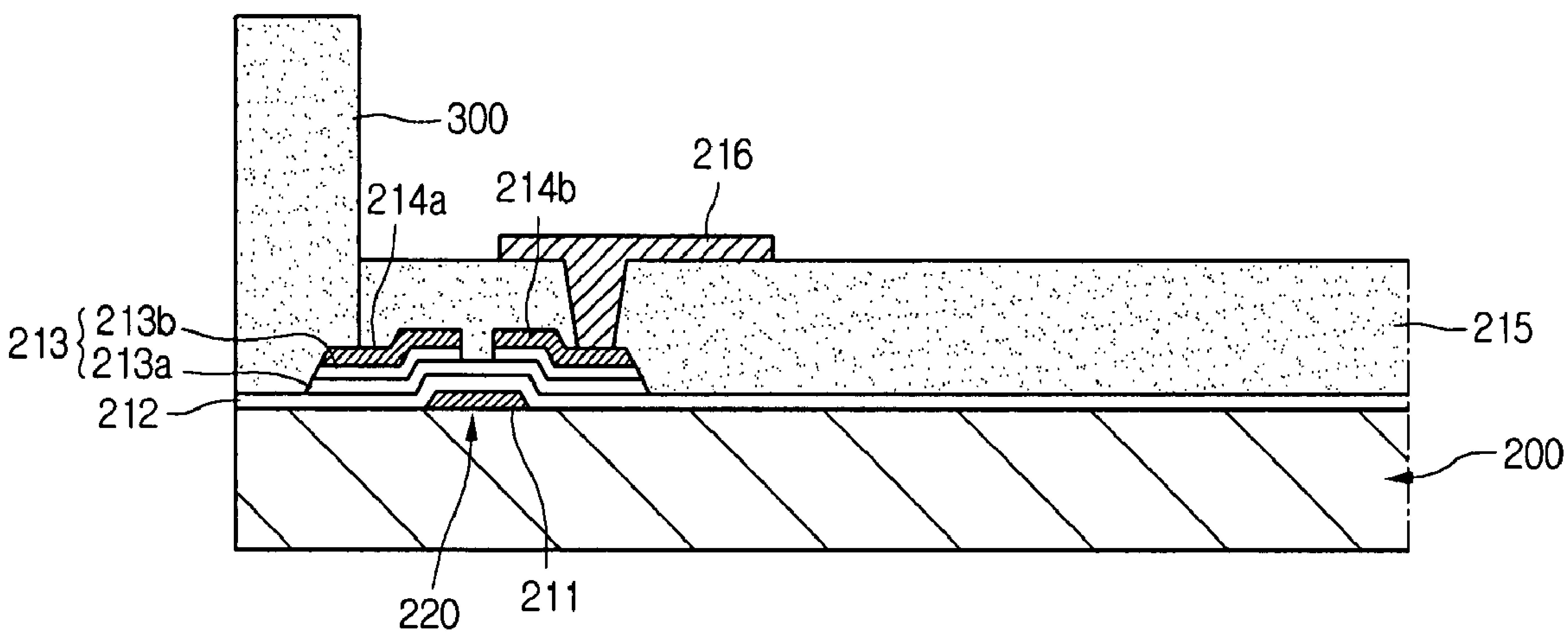


FIG. 12



ORGANIC LIGHT EMITTING DEVICE AND METHOD OF MANUFACTURING THE SAME

This invention claims the benefit of Korean Patent Application No. 10-2006-055239 filed in Korea on Jun. 20, 2006, and Korean Patent Application No. 10-2007-046037 filed in Korea on May 11, 2007, which are hereby incorporated by reference in their entirety.

BACKGROUND OF THE INVENTION

1. Field of the Invention

Embodiments of the present invention relate to a light emitting device, and more particularly, to an organic light emitting device and a method of manufacturing the same. Although embodiments of the invention are suitable for a wide scope of applications, it is particularly suitable for achieving a small device thickness, improving sharpness of an image, and simplifying a manufacturing process.

2. Description of the Related Art

Information processing equipment (IPE), and a display device that displays data of an electrical signal processed in the IPE in the form of an image has been developed. An example of a representative display device includes a liquid crystal display device, an organic light emitting device, or a plasma display panel. The liquid crystal display device displays an image using a liquid crystal, the organic light emitting device displays an image using an organic luminescent material, and the plasma display panel displays an image using a plasma. These display devices are mainly used for the IPE, such as computers, notebook computers, watches, mobile phones, MP3 players, or television receiver sets.

The organic light emitting device that displays an image using the organic luminescent material does not require a light supply unit, such as a backlight, and thus has a significantly small volume and weight. More specifically, the organic light emitting device includes a pair of conductive electrodes, and an organic luminescent layer interposed between the conductive electrodes. The organic luminescent layer includes an organic luminescent material. When a forward current is applied to the conductive electrodes of the organic light emitting device, light is generated from the organic luminescent layer. However, the related art organic light emitting device has problems of a complicated manufacturing process, a long manufacturing time, and a large overall thickness because an electron injection layer (EIL) and an electron transport layer (ETL) are formed on the electrode. Also, if the thicknesses of the electron injection layer and the electron transport layer of the related art organic light emitting device are not uniform, undesired light may be generated, causing image quality to considerably degrade, such as sharpness.

SUMMARY OF THE INVENTION

Accordingly, embodiments of the present invention is directed to an organic light emitting device and a method of manufacturing the same that substantially obviate one or more problems due to limitations and disadvantages of the related art.

An object of embodiments of the invention is to provide a single-layer electron transfer layer for providing electrons to the organic luminescent layer.

Additional features and advantages of embodiments of the invention will be set forth in the description which follows, and in part will be apparent from the description, or may be learned by practice of embodiments of the invention. The objectives and other advantages of the embodiments of the invention will be realized and attained by the structure particularly pointed out in the written description and claims hereof as well as the appended drawings.

To achieve these and other advantages and in accordance with the purpose of embodiments of the invention, as embodied and broadly described, an organic light emitting device includes a first electrode for providing holes, a second electrode facing the first electrode and providing electrons, an organic luminescent layer interposed between the first and second electrodes, and an electron transfer layer disposed between the second electrode and the organic luminescent layer, wherein the electron transfer layer is a single layer including electron transfer members so that the electron transfer layer injects and transports electrons to the organic luminescent layer while preventing holes from the first electrode from flowing into the electron transfer layer.

In another aspect, a method of manufacturing an organic light emitting device includes forming a second electrode on a substrate, forming a hole injection layer and a hole transport layer sequentially on the second electrode, forming an organic luminescent layer on the hole transport layer, forming an electron transfer layer, including a plurality of electron transfer members and an insulating layer, on the organic luminescent layer, and forming a first electrode on the electron transfer layer.

In another aspect, a method of manufacturing an organic light emitting device includes forming a first electrode on a substrate, forming an electron transfer layer, including a plurality of electron transfer members and an insulating layer, on the first electrode, forming an organic luminescent layer on the electron transfer layer, forming a hole transport layer a hole injection layer sequentially on the organic luminescent layer, and forming a second electrode on the a hole injection layer.

In yet another aspect, an organic light emitting device includes a first substrate having a display device having a first electrode the first substrate for providing holes, a second electrode facing the first electrode and providing electrons, an organic luminescent layer interposed between the first and second electrodes and an electron transfer layer disposed between the second electrode and the organic luminescent layer, wherein the electron transfer layer is a single layer including single-crystal silicon particles so that the electron transfer layer injects and transports electrons to the organic luminescent layer while preventing holes from the first electrode from flowing into the electron transfer layer, a second substrate having a driving device, and an encapsulating member joining the first and second substrate.

It is to be understood that both the foregoing general description and the following detailed description of the present invention are exemplary and explanatory and are intended to provide further explanation of the invention as claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a cross-sectional view of an organic light emitting device according to a first embodiment of the present invention;

FIG. **2** is a view for describing a process of forming an electron transfer layer of an organic light emitting device according to an embodiment of the present invention;

FIG. **3** is a cross-sectional view of an electron transfer member constituting an electron transfer layer of the organic light emitting device of FIG. **1**;

FIG. **4** is a cross-sectional view illustrating holes and electrons provided to an organic luminescent layer in the organic light emitting device of FIG. **1**;

FIG. **5** is a cross-sectional view of an organic light emitting device according to a second embodiment of the present invention;

FIG. **6** is a cross-sectional view of an electron transfer member constituting an electron transfer layer of the organic light emitting device of FIG. **5**;

FIG. **7** is a cross-sectional view illustrating holes and electrons provided to an organic luminescent layer of the organic light emitting device of FIG. **5**;

FIG. **8**A is a flowchart of a method of manufacturing an organic light emitting device according to a third embodiment of the present invention;

FIG. **8**B is a flowchart of a method of manufacturing an organic light emitting device according to a fourth embodiment of the present invention;

FIG. **9** is a cross-sectional view illustrating an organic light emitting device according to a fifth embodiment of the present invention;

FIGS. **10**A and **10**B are partial enlarged views of part A of FIG. **9**; and

FIGS. **11** and **12** are cross-sectional views for describing a method of manufacturing the organic light emitting device according to the fifth embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference will now be made in detail to the preferred embodiments of the present invention, examples of which are illustrated in the accompanying drawings. Embodiments of the invention may, however, be embodied in many different forms and should not be construed as being limited to the embodiments set forth herein. In the figures, the dimensions of layers and regions are exaggerated for clarity of illustration. It will also be understood that when a layer (or structure) is referred to as being 'on' or 'under' another layer or structure, it can be directly on or 'under' the other layer or substrate, or intervening layers may also be present. Also, though terms like a first, a second, and a third are used to describe various regions and layers in various embodiments of the present invention, the regions and the layers are not limited to these terms. These terms are used only to tell one region or layer from another region or layer. Therefore, a layer referred to as a first layer in one embodiment can be referred to as a second layer in another embodiment. An embodiment described and exemplified herein includes a complementary embodiment thereof.

FIG. **1** is a cross-sectional view of an organic light emitting device according to a first embodiment of the present invention, and FIG. **2** is a view for describing a process of forming an electron transfer layer of an organic light emitting device according to the first embodiment of the present invention. FIG. **3** is a cross-sectional view of an electron transfer member forming an electron transfer layer of the organic light emitting device of FIG. **1**, and FIG. **4** is a cross-sectional view illustrating holes and electrons provided to an organic luminescent layer of the organic light emitting device of FIG. **1**.

Referring back to FIG. **1**, the organic light emitting device **100** includes a first electrode **31**, a second electrode **32**, an organic luminescent layer **35**, and an electron transfer layer **33**. The organic light emitting device **100** can further include a substrate **20**, a hole injection layer **36**, and a hole transport layer **37**. The first electrode **31** is disposed on the substrate **20**, and the hole injection layer **36** and the hole transport layer **37** are sequentially disposed on the first electrode **31**. The organic luminescent layer **35** is disposed on the hole transport layer **37**, and the electron transfer layer **33** is disposed on the organic luminescent layer **35**. The substrate **20** can be, for example, a transparent glass substrate.

The first electrode **31** disposed on the transparent substrate **20** can include a transparent conductive material. For example, examples of a material used for the first electrode **31** include indium tin oxide (ITO), indium zinc oxide (IZO) and amorphous indium tin oxide (a-ITO).

The hole injection layer **36** disposed on the first electrode **31** can include, for example, Cu-phthalocyanine (CuPc). Although CuPc is used as an example of a material of the hole injection layer **36** in the current embodiment, various hole transport compounds can be used provided that those compounds serve to transport holes injected from the first electrode **31** to the organic luminescent layer **35**. For example, the hole injection layer **36** can include a hole-injectable polypyrine compound, a phthalocyanine compound, a hole-transportable aromatic tertiary amine, a trisphenothiazinyl triphenylamine derivative or a trisphenoxa-dinyltriphenylamine derivative, polythiopene, and a compound including a carbazole group. Alternatively, the hole injection layer **36** can include a triazole compound, an oxadiazole derivative, an imidazole derivative, a polyarylalkan derivative, a pyrazoline derivative, a pyrazolone derivative, a phenylenediamine derivative, an arylamine derivative, an oxazole derivative, a styrylanthracene derivative, a fluorine derivative, a hydrazone derivative, a stylbene derivative, a porphyrin compound, an aromatic tertiary amine compound, a styrylamine compound, a butadiene compound, a polystyrene derivative, a hydrazone derivative, a triphenylmethane derivative, a tetraphenylbenzidine derivative, a polyaniline based polymer material, a polythiophene-based polymer material, or a polypyrrole-based polymer material.

Referring to FIG. **1** again, the hole transport layer **37** is disposed on the hole injection layer **36**. The hole transport layer **37** efficiently transports holes provided from the first electrode **31** and the hole injection layer **36** to the organic luminescent layer **35**. The organic luminescent layer **35** can be disposed on the hole injection layer **36**. Alternatively, the organic luminescent layer **35** can be disposed directly on the first electrode **31**. Various polymer materials suited to the generation of red, green, blue light are used for the organic luminescent layer **35**.

The second electrode **32** provides electrons toward the organic luminescent layer **35**. The electrons provided from the second electrode **32**, and the holes provided from the first electrode **31** allow the organic luminescent layer **35** to generate red light, green light, and blue light depending on a polymer material forming the organic luminescent layer **35**. A material with a low work function can be used for the second electrode **32**, and examples of materials used for the second electrode **32** include aluminum and aluminum alloy. To efficiently transport electrons from the second electrode **32** to the organic luminescent layer **35**, the electron transfer layer **33** is formed the second electrode **32** and the organic luminescent layer **35**.

Referring to FIG. **3**, the electron transfer layer **33** has a single-layered structure. The single-layered electron transfer layer **33** serves as both an electron injection layer and an electron transport layer. The electron transfer layer **33** accelerates and transfers electrons from the second electrode **32** to the organic luminescent layer **35**. To inject and transport electrons from the second electrode **32** to the organic luminescent layer **35**, the electron transfer layer **33** includes a plurality of electron transfer members **33***c*. That is, the electron transfer layer **33** includes the electron transfer members **33***c* so that the electron transfer layer **33** injects and transports electrons to the organic luminescent layer **35** as a single layer.

The electron transfer members **33***c* include respective single-crystal silicon particles **33***b* and an insulating layer **33***a* encompassing each of the single-crystal silicon particles **33***b*. The electron transfer layer **33** is formed using a binder to provide the plurality of electron transfer members **33***c* as a thin film. The single-crystal silicon particles **33***b* can have a diameter ranging from about 50 Å to 100 Å. The insulating layer **33***a* encompassing the single-crystal silicon particles **33***b* is, for example, a silicon nitride layer (SiNx) or a silicon oxide layer (SiOx). The electron transfer members **33***c*, including the single-crystal silicon particles **33***b* within the insulating layer **33***a*, are disposed with a uniform thickness between the second electrode **32** and the organic luminescent layer **35**.

FIG. **2** is a view for describing a process of forming an electron transfer layer of an organic light emitting device according to an embodiment of the present invention. This method of forming the electron transfer layer **33** starts by radiating ultraviolet (UV) rays having a wavelength in a range of about 395 nanometers to about 415 nanometers onto cyclopentasilane (CPS, SixH2x) to cause a polymerization reaction, as illustrated in FIG. **2**. The resulting polymerized material is mixed with a volatile solution. Thereafter, polymerized material solution is coated onto the first electrode **31** or on the organic luminescent layer **35**. More specifically, the polymerized material solution can be inkjetted onto the first electrode **31** or on the organic luminescent layer **35**. Subsequently, the polymerized material coating is subjected to a heat treatment at about 500 degrees Celsius to about 600 degrees Celsius to form single-crystal silicon particles **33***b*. Thereafter, an insulating layer **33***a* is formed on the single-crystal silicon particles **33***b* by a deposition process to form the electron transfer members **33***c* of the electron transfer layer **33**. The insulating layer **33***a* can be a silicon nitride layer, a silicon oxide layer or an organic insulating layer. In the alternative, the insulating layer **33***a* can be deposited by a spin coating process or printing.

Another method of forming the electron transfer layer **33** starts by mixing nano powder type silicon particles with a volatile solution. Then, the silicon particle solution is coated onto the first electrode **31** or on the organic luminescent layer **35**. More specifically, the silicon particle solution can be inkjetted onto the first electrode **31** or on the organic luminescent layer **35**. Subsequently, the silicon particle coating is subjected to a heat treatment to form single-crystal silicon particles **33***b*. Thereafter, an insulating layer **33***a* is formed on the single-crystal silicon particles **33***b* by a deposition process to form the electron transfer members **33***c* of the electron transfer layer **33**. The insulating layer **33***a* can be a silicon nitride layer, a silicon oxide layer or an organic insulating layer. In the alternative, the insulating layer **33***a* can be deposited by a spin coating process or printing.

The thickness of the electron transfer layer **33**, including the electron transfer members **33***c*, measured between the organic luminescent layer **35** and the second electrode **32** can be in a range of about 300 Å to about 600 Å. If the thickness of the electron transfer layer **33** is smaller than about 300 Å, the number of electrons transferred to the organic luminescent layer **35** through the electron transfer layer **33** considerably decrease relative to the number of holes. In contrast, if the thickness of the electron transfer layer **33** is greater than about 600 Å, the number of electrons transferred to the organic luminescent layer **35** through the electron transfer layer **33** increase considerably relative to the number of holes.

Also, if the thickness of the electron transfer layer **33** is greater than about 600 Å, the entire thickness of the organic light emitting device **100** increases.

As illustrated in FIG. **4**, the electron transfer layer **33** injects and transports electrons to the organic luminescent layer **35**, and prevents holes provided from the first electrode **31** from flowing into the electron transfer layer **33**, thereby greatly improving sharpness of an image generated from the organic luminescent layer **35**. Since the electron transfer layer **33** for transferring electrons from the second electrode **32** to the organic luminescent layer **35** by accelerating the electrons is formed as a single layer, a manufacturing process of the organic light emitting device **100** can be shortened.

As mentioned above, the single-layered electron transfer layer, including the electron transfer members formed by encompassing each single-crystal silicon particle with an insulating layer, is disposed between the second electrode and the organic luminescent layer. Thus, the manufacturing process of the organic light emitting device, and the time for the manufacturing process are reduced. Also, light generation is prevented from occurring in the electron transfer layer, so that sharpness of an image obtained by light generated by the organic luminescent layer can be greatly improved.

FIG. **5** is a cross-sectional view of an organic light emitting device according to a second embodiment of the present invention, FIG. **6** is a cross-sectional view illustrating an electron transfer member forming an electron transfer layer of the organic light emitting device of FIG. **5**, and FIG. **7** is a cross-sectional view illustrating holes and electrons provided to an organic luminescent layer of the organic light emitting device of FIG. **5**. Referring to FIG. **5**, an organic light emitting device **200** according to a second embodiment is structurally similar to the organic light emitting device **100** of FIG. **1**, and thus like reference numerals and names are used for like elements of the same materials as those of FIG. **1**. Thus, the following description is mainly focused on an electron transfer layer **43**, and the detailed descriptions of other elements refer to FIGS. **1** through **4**.

The organic light emitting device **200** includes a first electrode **31**, a second electrode **32**, an organic luminescent layer **35**, and an electron transfer layer **43**. The organic light emitting device **200** can further include a substrate **20**, a hole injection layer **36** and a hole transfer layer **37**.

The first electrode **31** is disposed on the substrate **20**, and the hole injection layer **36** and the hole transport layer **37** are sequentially disposed on the first electrode **31**. The organic luminescent layer **35** is disposed on the hole transport layer **37**, and the electron transfer layer **43** is disposed on the organic luminescent layer **35**.

As illustrated in FIG. **5**, the hole transport layer **37** is disposed on the hole injection layer **36**. The hole transport layer **37** efficiently transports holes provided from the first electrode **31** and the hole injection layer **36** to the organic luminescent layer **35**. To efficiently transport electrons provided from the second electrode **32** to the organic luminescent layer **35**, the electron transfer layer **43** is formed between the second electrode **32** and the organic luminescent layer **35**.

Referring to FIG. **7**, the electron transfer layer **43** has a single-layered structure. The single-layered electron transfer layer **43** serves as an electron injection layer and an electron transport layer. That is, the electron transfer layer **43** accelerates and transfers electrons from the second electrode **32** to the organic luminescent layer **35**. The electron transfer layer **43** includes a plurality of electron transfer members **43***c* to inject and transport electrons from the second electrode **32** to the organic luminescent layer **35**. Since the electron transfer layer **43** includes the electron transfer members **43***c*, the electron transfer layer **43** can inject and transport electrons to the organic luminescent layer **35** as a single-layered structure.

Each of the electron transfer members **43***c* is a single-crystal silicon particle **43***b* in an insulating layer **43***a*. The single-crystal silicon particle **43***b* can have a diameter ranging from about 50 Å to 100 Å. Also, the insulating layer **43***a* can be, for example, a silicon nitride layer (SiNx) or a silicon oxide layer (SiOx). The electron transfer members **43***c* within the insulating layer **43***a* are disposed with a uniform thickness between the second electrode **32** and the organic luminescent layer **35**.

The thickness of the electron transfer layer **43**, including the electron transfer members **43***c*, measured between the organic luminescent layer **35** and the second electrode **32** can be in a range of about 300 Å to about 600 Å. When the thickness of the electron transfer layer **43** is smaller than about 300 Å, the number of electrons transported to the organic luminescent layer **35** through the electron transfer layer **43** can considerably decrease relative to the number of holes. If the thickness of the electron transfer layer **43** is greater than about 600 Å, the number of electrons transported to the organic luminescent layer **35** through the electron transfer layer **43** can considerably increase relative to the number of holes. Also, if the thickness of the electron transfer layer **43** is greater than about 600 Å, the entire thickness of the organic light emitting device **100** can increase.

As illustrated in FIG. **7**, the electron transfer layer **43** according to a second embodiment of the present invention injects and transports electrons to the organic luminescent layer **35**, and prevents holes provided from the first electrode **31** from flowing into the electron transfer layer **43**, thereby greatly improving sharpness of an image generated from the organic luminescent layer **35**. As the electron transfer layer **43** accelerating and transporting electrons provided from the second electrode **32** to the organic luminescent layer **35** is formed as a single layer, a manufacturing process of the organic light emitting device **100** can be reduced.

As mentioned above, the single-layered electron transfer layer including the electron transfer members each formed by deposition of the insulating layer for single-crystal silicon particles disposed between the second electrode and the organic luminescent layer. Thus, the manufacturing process of the organic light emitting device, and the time for the manufacturing process are reduced. Also, light generation is prevented from occurring at the electron transfer layer, so that sharpness of an image formed by light generated by the organic luminescent layer can be greatly improved.

FIG. **8**A is a flowchart illustrating a manufacturing method of an organic light emitting device according to a third embodiment of the present invention. Referring to FIGS. **1**, **5** and **8**A, a manufacturing method of the organic light emitting device will now be described. In step S**10**, a first electrode **31** is formed on a substrate **20**, such as a glass substrate. A transparent conductive layer (not shown) is formed on the substrate **20** to form the first electrode **31**. The transparent conductive layer can be formed of, for example, an indium tin oxide (ITO), an indium zinc oxide (IZO), or an amorphous indium tin oxide (a-ITO). A photoresist film is formed on the transparent conductive layer. The photoresist film is patterned by a photo-process, including an exposure process and a development process to form a photoresist pattern on the transparent conductive layer. The transparent conductive layer is patterned using the photoresist pattern as an etch mask to form the first electrode **31** on the substrate **20**.

In step S**20**, a hole injection layer **36** and a hole transport layer **37** are sequentially formed on the first electrode **31**. The hole injection layer **36** and the hole transport layer **37** can be formed by a vacuum deposition process.

In step S**30**, after the hole injection layer **36** and the hole transport layer **37** are formed on the first electrode **31**, an organic luminescent layer **35** is formed on the hole transport layer **37**. The organic luminescent layer **35** can be formed by a vacuum deposition process. The organic luminescent layer **35** can include a polymer material that can generate red light, green light and blue light by combination of holes provided through the hole injection layer **36** and the hole transport layer **37**, and electrons transported by an electron transfer layer to be described later.

In step S**40**, an electron transfer layer **33**(**43**) is formed on the organic luminescent layer **35**. Referring to FIGS. **3** and **6**, the electron transfer layer **33**(**43**) includes a plurality of electron transfer members **33***c*(**43***c*). The electron transfer members **33***c*(**43***c*) can be formed by coating powder type single-crystal silicon particles **33***b*(**43***b*), or the single crystal silicon particles **33***b*(**43***b*) can be formed UV radiation. After the powder type single-crystal silicon particles **33***b*(**43***b*) are formed, the insulating layer **33***a*(**43***a*) is formed. The insulating layer **33***a*(**43***a*) is formed of silicon nitride (SiNx) or silicon oxide (SiOx).

The single-layered electron transfer layer **33**(**43**), including the electron transfer members **33***c*(**43***c*) with the insulating layer **33***a*(**43***a*) coating the single-crystal silicon particles **33***b*(**43***b*), efficiently transports electrons provided from a second electrode **32** to be described later to the organic luminescent layer **35**. The electron transfer layer **33**(**43**) is formed by mixing powder type single-crystal silicon particles with a solvent or a volatile solution, and forming a resulting mixture on the organic luminescent layer **35**, and then forming the insulating layer **33***a*(**43***a*) thereon. Alternatively, the electron transfer layer **33**(**43**) is formed by forming single-crystal silicon particles into a thin film using a UV polymerization reaction, and then forming the insulating layer **33***a*(**43***a*) thereon.

The insulating layer **33***a*(**43***a*) is formed by depositing a silicon nitride layer or a silicon oxide layer to form the electron transfer members **33***c* as illustrated FIG. **3**, or form the electron transfer members **43***c* as illustrated in FIG. **6**. When the single-crystal silicon particles **33***b* are formed on the organic luminescent layer **35** and then the insulating layer **33***a* is formed by a spin coating process, the transfer member **33***c*, as illustrated in FIG. **3**, is formed. Alternatively, when the insulating layer **43***a* is formed by a deposition process, the transfer member **43***c*, as illustrated in FIG. **6**, is formed. Also, an application and solvent-removing process for applying a mixture, including the electron transfer members **33***c*(**43***c*), on the organic luminescent layer **35** and forming a preliminary electron transfer layer includes a dry process using a heat treatment. The application process includes providing a mixture of a binder and the electron transfer members **33***c*(**43***c*) on the organic luminescent layer **35** through a silk screen process, a slit coating process, or a spin coating process.

The thickness of the electron transfer layer **33**(**43**) measured from a surface of the organic luminescent layer **35** can range from about 300 Å to 600 Å. In step S**50**, after the electron transfer layer **33**(**43**) is formed on the organic luminescent layer **35**, a second electrode **32** is formed on the electron transfer layer **33**(**43**). The second electrode **32** can be formed of, for example, aluminum, or aluminum alloy. The second electrode **32** provides electrons to the electron transfer layer **33**(**43**).

FIG. **8**B is a flowchart of a manufacturing method of an organic light emitting device according to a fourth embodiment of the present invention. Referring to FIGS. **1**, **5** and **8**B, the manufacturing method of the organic light emitting device according to the fourth embodiment will now be described. In steps S**60** and S**70**, a second electrode **32** is formed of a conductive metal, such as aluminum, or aluminum alloy, and then an electron transfer layer **33**(**43**) is formed on the second electrode **32**. As described with reference to FIG. **8**A, referring to FIGS. **3** and **6**, the electron transfer layer **33**(**43**) includes a plurality of electron transfer members **33***c*(**43***c*). The electron transfer members **33***c*(**43***c*) include respective single-crystal silicon particles **33***b*(**43***b*) formed using powder type silicon particles or formed by UV polymerization reactions, and an insulating layer **33***a*(**43***a*) that is used to coat the single-crystal silicon particles **33***b* (**43***b*) or is deposited on the single-crystal silicon particles **33***b*(**43***b*). The insulating layer **33***a*(**43***a*) is formed of one of silicon nitride (SiNx), silicon oxide (SiOx) and an organic insulating material.

The single-layered electron transfer layer **33**(**43**), including the electron transfer members **33***c*(**43***c*) having the single-crystal silicon particles **33***b*(**43***b*) coated with the insulating layer **33***a*(**43***a*) or the insulating layer **33***a*(**43***a*) deposited thereon, transports electrons provided from the second electrode **32** efficiently to an organic luminescent layer **35** to be described later. The electron transfer layer **33**(**43**) is formed by mixing powder type single-crystal silicon particles with a solvent or a volatile solution, forming a resulting mixture on the second electrode **32**, and then forming the insulating layer **33***a*(**43***a*) thereon. Alternatively, the electron transfer layer **33**(**43**) is formed by forming on the second electrode **32** single-crystal silicon particles into a thin film type using a UV polymerization reaction, and then forming the insulating layer **33***a*(**43***a*) thereon.

The insulating layer **33***a*(**43***a*) is formed by coating or depositing a silicon oxide layer or a silicon nitride layer, thereby forming the electron transfer member **33***c*, as illustrated in FIG. **3**, or forming the electron transfer member **43***c*, as illustrated in FIG. **6**. When the insulating layer **33***a* is formed by a coating process after the single-crystal silicon particles **33***b* are formed on the second electrode **32**, the electron transfer members of FIG. **3** are formed. When the insulating layer **43***a* is formed by a deposition process, the electron transfer members **43***c* of FIG. **6** are formed. Also, an application and solvent-removing process of applying a mixture, including the electron transfer members **33***c*(**43***c*), on the second electrode **32** and forming a preliminary electron transfer layer **33**(**43**) includes a dry process using a heat treatment. The thickness of the electron transfer layer **33**(**43**) can range from about 300 Å to 600 Å.

When the electron transfer layer is formed in the above manner, an organic luminescent layer **35** is formed on the electron transfer layer in step S**80**. The organic luminescent layer **35** can be formed by vacuum deposition or spin-coating. In the current embodiment, the organic luminescent layer **35** can include a polymer material that can generate red light, green light and blue light by combination of holes provided through a hole injection layer **36** and a hole transport layer **37** to be described later, and electrons transported by the electron transfer layer.

In steps S**90** and S**100**, when the organic luminescent layer **35** is formed, the hole transport layer **37** and the hole injection layer **36** are sequentially formed, and a first electrode **31** is formed on the hole injection layer **36**. A substrate **20** formed of a transparent insulating material is formed on the first electrode **31**.

FIG. **9** is a cross-sectional view illustrating an organic light emitting device according to a fifth embodiment of the present invention, and FIGS. **10**A and **10**B are enlarged views of part "A" of FIG. **9**. Referring to FIGS. **9** and **10**, an organic light emitting device **500** includes a first substrate **105**, a second substrate **200**, and an encapsulating member **300**.

The first substrate **105** can be a transparent substrate having substantially the same light transmittance as that of glass. The first substrate **105** can be a glass substrate. The first substrate **105** includes a first surface **101** facing the second substrate **200**, a second surface **102** facing the first surface **101**, and side surfaces **103** connecting the first and second surfaces **101** and **102**.

The second substrate **200** can be, for example, a transparent substrate having substantially the same light transmittance as that of glass. Alternatively, the second substrate **200** can be an opaque substrate. The second substrate **200** includes a third surface **201** facing the first surface **101**, a fourth surface **202** facing the third surface **201**, and side surfaces **203** connecting the third and fourth surfaces **201** and **202**.

A display device **170** is disposed on the first surface **101** of the first substrate **105**. The display device **107** includes an auxiliary electrode pattern **110**, a first electrode **120**, partition wall patterns **130**, organic light emitting patterns **140**, a second electrode **150**, and a spacer **160**.

The auxiliary electron pattern **110** is disposed on the first surface **101** of the first substrate **105**. When viewed from the plane, the auxiliary electrode pattern **110** has a lattice shape. Examples of a material used for the auxiliary electrode pattern **110** can include molybdenum, aluminum, copper, and chrome. The auxiliary electrode pattern **110** serves to reduce electrical resistance of the first electrode **120** to be described later.

The first electrode **120** is disposed on the first surface **101** of the first substrate **105**, and covers the auxiliary electrode pattern **110**. In the current embodiment, examples of a material used for the first electrode **120** can include indium tin oxide (ITO), indium zinc oxide (IZO), and amorphous indium tin oxide (a-ITO).

The partition wall patterns **130** are disposed on the first electrode **120**, and form a pixel area on the first electrode **120**. The number of partition wall patterns **130** corresponds to a resolution of the organic light emitting device **500**. The partition wall patterns **130** are spaced apart from each other at a predetermined interval, and have a quadrangular frame shape having therein an opening exposing the first electrode **120**.

The spacer **160** is disposed on the first electrode **120**. Alternatively, a portion of the spacer **160** can overlap the partition wall pattern **130**. The spacer **160** is formed in each pixel area defined by the partition wall patterns **130**. The spacer **160** can have, for example, a column shape. The height of the spacer **160** measured from a surface of the first electrode **120** is greater than the height of the partition wall pattern **130** measured from a surface of the first electrode **120**.

The organic light emitting patterns **140** are disposed on the first electrode **120** exposed by the partition wall patterns **130**, and on the partition wall patterns **130** by self-alignment.

Referring to FIGS. **10**A and **10**B, the organic light emitting pattern **140** formed on the first electrode **120** can include a hole injection layer **141**, a hole transport layer **142**, an organic luminescent layer **144**, and an electron transfer layer **146** (**246**). The hole transport layer **142** is disposed on the hole injection layer **141**. The hole transport layer **142** efficiently transports holes provided from the first electrode **120** and the hole injection layer **141** to the organic luminescent layer **144**.

The organic luminescent layer **144** can be disposed on the hole injection layer **141**. Alternatively, the organic luminescent layer **144** can be disposed directly on the first electrode. As the organic luminescent layer **144**, various polymer materials suitable to generate red, green and blue light can be used.

The electron transfer layer **146**(**246**) is interposed between a second electrode **150** to be described later, and the organic luminescent layer **144**.

Referring to FIGS. **10**A and **10**B, the electron transfer layer **146**(**246**) has a single-layered structure, and the single-layered electron transfer layer **146**(**246**) serves as an electron injection layer and an electron transport layer. That is, the electron transfer layer **146**(**246**) injects and transports electrons from the second electrode **150** to be described later to the organic luminescent layer **144**.

The electron transfer layer **146**(**246**) includes a plurality of electron transfer members **145**(**245**) to inject and transport electrons from the second electrode **150** to the organic luminescent layer **144**. The electron transfer members **145**(**245**) include respective single-crystal silicon particles and an insulating layer coating the single-crystal silicon particles. The single-crystal silicon particle can have a diameter ranging from about 50 Å to 100 Å. Also, the insulating layer used to coat the single-crystal silicon particles can be, for example, a silicon nitride layer or a silicon oxide layer.

As described above, the single-crystal silicon particles are prepared by mixing powder type single-crystal silicon particles with a solvent or a volatile solution or by radiating UV rays to a mixture including single-crystal silicon particles to cause a polymerization reaction. FIG. **10**A is a view of the case where the single-crystal silicon particles prepared in the above manner are coated with an insulating layer, and FIG. **10**B is a view of forming single-crystal silicon particles and depositing an insulating layer thereon. The electron transfer layer **146**(**246**), including the electron transfer members **145** (**245**), is disposed with a uniform thickness between the second electrode **150** and the organic luminescent layer **144**.

In the current embodiment, the thickness of the electron transfer layer **146**(**246**), including the electron transfer members **145**(**245**), measured between the organic luminescent layer **144** and the second electrode can be in range about 300 Å to about 600 Å. If the thickness of the electron transfer layer **146**(**246**) is smaller than about 300 Å, the number of electrons transported to the organic luminescent layer **144** through the electron transfer layer **146**(**246**) can greatly decrease relative to the number of holes. In contrast, if the thickness of the electron transfer layer **146**(**246**) is greater than about 600 Å, the number of electrons transported to the organic luminescent layer **144** through the electron transfer layer **146**(**246**) can greatly increase relative to the number of holes. Also, if the thickness of the electron transfer layer **144** is greater than about 600 Å, the entire thickness of the organic light emitting device **500** can increase.

The second electrode **150** is disposed on the electron transfer layer **146**(**246**). The second electrode **150** transfers electrons to the organic luminescent layer **144**. Electrons provided from the second electrode **150**, and holes provided from the first electrode **120** allows the organic luminescent layer **144** to generate red light, green light, and blue light depending on a polymer material of the organic luminescent layer **144**. The second electrode **150** can be formed of a material with a low work function, and examples of the material of the second electrode **150** include aluminum and aluminum alloy.

Referring to FIG. **9** again, a driving device **210** is disposed on the third surface **201** of the second substrate **200** to drive the display device **170** disposed on the first surface **101** of the first substrate **105**. To drive the display device **170**, the driving device **210** can include, for example, two thin film transistors **220** and one capacitor (not shown). Each of the thin film transistors **220** includes a gate electrode **211**, a gate insulating layer **212**, a channel layer **213**, a source electrode **214***a* and a drain electrode **214***b*. The gate electrode **211** is electrically connected to a gate line (not shown) disposed on the third surface **201**, and a timing signal is applied to the gate electrode **211**. The gate insulating layer **212** insulates the gate electrode **211** and the gate line. The gate insulating layer **212** can be an oxide layer or a nitride layer. The channel layer **213** is disposed on the gate insulating layer **212**. The channel layer **213** faces the gate electrode **211** covered with the gate insulating layer **212**.

The channel layer **213** includes an amorphous silicon pattern **213**, and n+ amorphous silicon patterns **213***b*. The amorphous silicon pattern **213***a* is disposed on the gate insulating layer **212**, and the n+ amorphous silicon patterns **213** are disposed on the amorphous silicon pattern **213***a*. A pair of amorphous silicon patterns **213***b* are disposed on the amorphous silicon pattern **213***b*, and the amorphous silicon patterns **213***b* are spaced apart from each other.

The source electrode **214***a* is electrically connected to any one of the n+ amorphous silicon patterns **213***b*, and the drain electrode **214***b* is electrically connected to the remaining n+ amorphous silicon pattern **213***b*.

The thin film transistor **220** is insulated by an organic layer pattern **215** including a contact hole exposing the drain electrode **214***b*, and the drain electrode **214***b* of the thin film transistor **220** is electrically connected to a connection pattern **216**.

The second electrode **150** of the display device **170** formed on the first substrate is electrically connected to the connection pattern **216** of the thin film transistor **220** of the driving unit **210** formed on the second substrate **200**.

When viewed from the plane, the encapsulating member **300** can have a closed loop shape along an edge of the first substrate **105** and/or the second substrate **200**. For the physical coupling between the first and second substrates **100** and **200**, the encapsulating member **300** can include a thermosetting material hardened by heat, and a photocurable material hardened by light, such as UV light. Also, the encapsulating member **300** can include a degradation preventing material that prevents the display device **170** from being degraded due to coupling of the encapsulating member **300** with oxygen and/or moisture penetrating from the outside. The degradation preventing material can include an alkali-based metal oxide or an alkali-based metal.

FIGS. **11** and **12** are cross-sectional views for describing a manufacturing method of an organic light emitting device according to the fifth embodiment of the present invention. Referring to FIG. **11**, an auxiliary electrode pattern **110** is formed on a first substrate **105**. In the current embodiment, the auxiliary electrode pattern **110** has a lattice shape when viewed from the plane. The auxiliary electrode pattern **110** serves to reduce electrical resistance of a first electrode **120** to be described later. The auxiliary electrode pattern **110** can be formed of, for example, molybdenum, aluminum, cooper, or chrome.

After the auxiliary electrode pattern **110** is formed on the first substrate **105**, then the first electrode **120** covering the auxiliary electrode pattern **110** is formed on the first substrate **105**.

After the first electrode **120** is formed, an organic sacrificial layer pattern (not shown) including a photoresist material is formed on the first electrode **120** facing the auxiliary electrode pattern **110**. Since the auxiliary electrode pattern **110** has a lattice shape, the organic sacrificial layer pattern also has a lattice shape when viewed from the plane.

After the organic sacrificial layer pattern is formed, an inorganic layer (not shown) covering the first electrode **120** and the organic sacrificial layer pattern is formed.

Thereafter, the inorganic layer is patterned to form partition wall patterns **130** on the first electrode **120**. The partition wall patterns **130** have a quadrangular frame shape. Adjacent partition wall patterns **130** expose an upper surface of the organic sacrificial layer pattern.

After the partition wall patterns **130** exposing an upper surface of the organic sacrificial layer pattern is formed, the organic sacrificial pattern is removed from the first electrode **120** by an etchant or an etching gas.

After the organic sacrificial layer pattern is removed from the first electrode **120**, a spacer **160** with a column shape is formed on the first electrode **120**. The spacer **160** can be formed on the first electrode **120** or the partition wall pattern **130** by patterning an organic layer.

Thereafter, as illustrated in FIGS. **10**A and **10**B, a hole injection hole **141**, a hole transport layer **142**, and an organic luminescent layer **144** are sequentially formed on an entire surface of the first substrate. The hole injection layer **141**, the hole transport layer **142**, and the organic luminescent layer **144** can be formed by a vacuum deposition method. The organic luminescent layer **144** can include a polymer material that can generate red light, green light and blue light by combination of holes provided through the hole injection layer **141** and the hole transport layer **142**, and electrons transported by an electron transfer layer **146**(**246**) to be described later.

The electron transfer layer **146**(**246**) is formed on the organic luminescent layer **144**. The electron transfer layer **146**(**246**) includes a plurality of electron transfer members **145**(**245**). The electron transfer members **145**(**245**) include respective single-crystal silicon particles of a powder type, and an insulating layer coating each of the single-crystal silicon particles. The single-layered electron transfer layer **146**(**246**), including the electron transfer members **145**(**245**) having the single-crystal silicon particles **145***a* coated with the insulating layer efficiently transfers electrons provided from a second electrode **150** to be described later to the organic luminescent layer **144**. An application process and a dry process are performed. In the application process, a mixture obtained by mixing the electron transfer members **145** (**245**) with a binder dissolved in a solvent and having adhesiveness and volatility is applied on the organic luminescent layer **144** to form a preliminary electron transfer layer. In the dry process, the solvent of the binder is removed. The mixture, including the binder and the electron transfer member **145**(**245**) can be applied on the organic luminescent layer **144** by a silk screen process, a slit-coating process, or a spin-coating process. The thickness of the electron transfer layer **146**(**246**) measured from a surface of the organic luminescent layer **144** can range from about 300 Å to 600 Å.

After the electron transfer layer **146**(**246**) is formed on the organic luminescent layer **144**, the second electrode **150** is formed on the electron transfer layer **146**(**246**). The second electrode **150** can be formed of, for example, aluminum, or aluminum alloy. The second electrode **150** provides electrons to the electron transfer layer **146**(**246**).

As illustrated in FIG. **12**, a driving device **210** for applying a driving signal for generation of light from the display device **170** on the first substrate **105** is manufactured on the second substrate **200**. The driving device **210** includes thin film transistors **220** such as a switching transistor and a driving transistor, and a capacitor (not shown). To form the thin film transistors **220**, a gate electrode **211** is formed on the second substrate **200**, and a gate insulating layer **212** covering the gate electrode **211** is formed on the gate electrode **211**. A channel layer **213** including an amorphous silicon pattern **213***a*, and a pair of n+amorphous silicon patterns **213***b* is formed on the gate insulating layer **212**. A source electrode **214***a* is formed on any one of the n+ amorphous silicon pattern **213***b*, and a drain electrode **214***b* is formed on the remaining n+ amorphous silicon pattern **213***b*.

After the driving device **220** is manufactured on the second substrate **200**, an organic layer pattern **215** covering the driving device **210** and having an opening exposing the drain electrode **214***b* of the thin film transistor **220** is formed on the second substrate **200**. Thereafter, a connection pattern **216** connected to the drain electrode **214***b* is formed at the opening of the organic layer pattern, thereby completing the second substrate **200**.

After the first substrate **105** including the display device **170**, and the second substrate **200** including the driving device **210** are manufactured as illustrated in FIGS. **11** and **12**, an encapsulating member **300** is formed at one of the first substrate facing the second substrate **200** and the second substrate **200** facing the first substrate **105**. When viewed from the plane, the encapsulating member **300** can have a closed loop shape formed along an edge of the second substrate **200**. The encapsulating member **300** can include a thermosetting material hardened by heat, or a photocurable material hardened by light such as UV light. Also, the encapsulating member **300** can include a degradation preventing material that prevents the display device **170** from being degraded due to coupling of the encapsulating member **300** with oxygen and/or moisture penetrating from the outside. The degradation preventing material can include an alkali-based metal oxide or an alkali-based metal.

After the encapsulating member **300** is disposed along the edge of the second substrate **200**, the first substrate **105** and the second substrate **200** are coupled by the encapsulating member **300**. The second electrode **150** of the first substrate **105** is electrically connected to a connection pattern **216** of the second substrate **200** by the encapsulating member **300**. After the second electrode **150** of the first substrate **105**, and the connection pattern **216** of the second substrate **200** are electrically connected together, the encapsulating member **300** is hardened by heat or light to make a physical/electrical connection between the first and second substrates **100** and **200**, thereby completing the manufacturing of the organic light emitting device.

As so far described in detail, unlike the related art electron transfer layer having a multi-layered structure, the organic light emitting device according to embodiments of the present invention includes the electron transfer layer having a single-layer structure that provides electrons to the organic luminescent layer. The single-layer electron transfer layer includes electron transfer members having single-crystal silicon particles encompassed by an insulating layer. Accordingly, a manufacturing process of the organic light emitting device can be considerably reduced.

It will be apparent to those skilled in the art that various modifications and variations can be made in the present invention. Thus, it is intended that the present invention covers the modifications and variations of this invention provided they come within the scope of the appended claims and their equivalents.

What is claimed is:

1. An organic light emitting device comprising:

a first electrode for providing holes;

a second electrode facing the first electrode and providing electrons;

an organic luminescent layer interposed between the first and second electrodes; and

an electron transfer layer disposed between the second electrode and the organic luminescent layer, wherein the electron transfer layer is a single layer including electron transfer members so that the electron transfer layer injects and transports electrons to the organic luminescent layer while preventing holes from the first electrode from flowing into the electron transfer layer, and

wherein the electron transfer members include single-crystal silicon particles.

2. The organic light emitting device according to claim **1**, wherein each of the single-crystal silicon particles can have a diameter ranging from about 50 Å to about 100 Å.

3. The organic light emitting device according to claim **1**, wherein each of the single-crystal silicon particles is encompassed by an insulating layer.

4. The organic light emitting device according to claim **3**, wherein the insulating layer is one of silicon nitride, silicon oxide and an organic insulating layer.

5. The organic light emitting device according to claim **4**, wherein each single-crystal silicon particles encompassed within the insulating layer is disposed with a uniform thickness between the second electrode and the organic luminescent layer.

6. The organic light emitting device according to claim **1**, wherein the single-crystal silicon particles are in an insulating layer.

7. The organic light emitting device according to claim **6**, wherein the insulating layer is one of silicon nitride, silicon oxide and an organic insulating material.

8. The organic light emitting device according to claim **1**, wherein a thickness of the electron transfer layer, including the electron transfer members, measured between the organic luminescent layer and the second electrode is within a range of about 300 Å to about 600 Å.

9. A method of manufacturing an organic light emitting device, comprising:

forming a second electrode on a substrate;

forming a hole injection layer and a hole transport layer sequentially on the second electrode;

forming an organic luminescent layer on the hole transport layer;

forming an electron transfer layer, including a plurality of electron transfer members and an insulating layer, on the organic luminescent layer; and

forming a first electrode on the electron transfer layer,

wherein the forming the electron transfer layer includes,

mixing powder type single-crystal silicon particles with a volatile solution;

applying a resulting mixture on the organic luminescent layer; and

forming the insulating layer on the single-crystal silicon particles.

10. The method of manufacturing an organic light emitting device according to claim **9** wherein the forming the insulating layer includes depositing by one of spin coating and printing.

11. The method of manufacturing an organic light emitting device according to claim **9**, wherein the applying the resulting mixture includes inkjetting the resulting mixture onto the organic luminescent layer.

12. The method of manufacturing an organic light emitting device according to claim **9**, wherein the insulating layer is one of silicon nitride, silicon oxide and an organic insulating material.

13. A method of manufacturing an organic light emitting device, comprising:

forming a first electrode on a substrate;

forming an electron transfer layer, including a plurality of electron transfer members and an insulating layer, on the first electrode;

forming an organic luminescent layer on the electron transfer layer;

forming a hole transport layer a hole injection layer sequentially on the organic luminescent layer; and

forming a second electrode on the a hole injection layer,

wherein the forming the electron transfer layer includes,

mixing powder type single-crystal silicon particles with one of a solvent and a volatile solution;

applying a resulting mixture on the first electrode; and

forming the insulating layer on the single-crystal silicon particles.

14. The method of manufacturing an organic light emitting device according to claim **13**, wherein the forming the insulating layer includes depositing by one of spin coating and printing.

15. The method of manufacturing an organic light emitting device according to claim **13**, wherein the applying the resulting mixture includes inkjetting the resulting mixture onto the first electrode.

16. The method of manufacturing an organic light emitting device according to claim **13**, wherein the insulating layer is one of silicon nitride, silicon oxide and an organic insulating material.

17. An organic light emitting device comprising:

a first substrate having a display device including:

a first electrode on the first substrate for providing holes;

a second electrode facing the first electrode and providing electrons;

an organic luminescent layer interposed between the first and second electrodes; and

an electron transfer layer disposed between the second electrode and the organic luminescent layer,

wherein the electron transfer layer is a single layer including single-crystal silicon particles so that the electron transfer layer injects and transports electrons to the organic luminescent layer while preventing holes from the first electrode from flowing into the electron transfer layer;

a second substrate having a driving device; and

an encapsulating member joining the first and second substrate.

18. The organic light emitting device according to claim **17**, wherein the single-crystal silicon particles are in an insulating layer.

19. The organic light emitting device according to claim **17**, wherein each of the single-crystal silicon particles is encompasses by an insulating layer.

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